

What is claimed is:

1. A method of producing purified water and sodium chloride from salt water that contains sodium chloride, the method comprising:
  - feeding the salt water to a reverse osmosis unit;
  - 5 operating the reverse osmosis unit to separate the salt water into a permeate of purified water which is recovered and a retentate that contains sodium chloride that is concentrated with reference to the salt water;
  - feeding the retentate to an electrodialysis unit having a plurality of
  - 10 membranes, wherein at least one electrodialysis membrane is a univalent anion-selective membrane and at least one other electrodialysis membrane is a univalent cation-selective membrane;
  - operating the electrodialysis unit to separate the retentate into a diluate that is depleted in sodium chloride with reference to the retentate,
  - 15 and a concentrate that is concentrated in sodium chloride with reference to the retentate, wherein at least a portion of the diluate is recycled back to the feed to the reverse osmosis unit;
  - feeding the concentrate to a salt-recovery unit; and
  - operating the salt-recovery unit to recover sodium chloride from the
  - 20 concentrate.
2. The method according to claim 1, wherein the salt water is seawater or is a salt water that is different than seawater and which contains sodium chloride and magnesium and bromine, or salts thereof.
- 25 3. The method according to claim 1, wherein the electrodialysis membranes include at least one anion exchange membrane, at least one cation exchange membrane, at least one univalent-anion selective membrane and at least one univalent-cation selective membrane.
- 30 4. The method according to claim 3, wherein the electrodialysis unit comprises an anode and a cathode and wherein at least four adjacent

electrodialysis membranes are arranged in the following order from the anode to the cathode: anion exchange, cation exchange, univalent anion-selective, and univalent cation-selective, wherein the order can be optionally repeated in whole or in part within the plurality of electrodialysis membranes.

5  
10  
15  
20  
25  
30  
35  
40  
45  
50  
55  
60  
65  
70  
75  
80  
85  
90  
95  
100  
105  
110  
115  
120  
125  
130  
135  
140  
145  
150  
155  
160  
165  
170  
175  
180  
185  
190  
195  
200  
205  
210  
215  
220  
225  
230  
235  
240  
245  
250  
255  
260  
265  
270  
275  
280  
285  
290  
295  
300  
305  
310  
315  
320  
325  
330  
335  
340  
345  
350  
355  
360  
365  
370  
375  
380  
385  
390  
395  
400  
405  
410  
415  
420  
425  
430  
435  
440  
445  
450  
455  
460  
465  
470  
475  
480  
485  
490  
495  
500  
505  
510  
515  
520  
525  
530  
535  
540  
545  
550  
555  
560  
565  
570  
575  
580  
585  
590  
595  
600  
605  
610  
615  
620  
625  
630  
635  
640  
645  
650  
655  
660  
665  
670  
675  
680  
685  
690  
695  
700  
705  
710  
715  
720  
725  
730  
735  
740  
745  
750  
755  
760  
765  
770  
775  
780  
785  
790  
795  
800  
805  
810  
815  
820  
825  
830  
835  
840  
845  
850  
855  
860  
865  
870  
875  
880  
885  
890  
895  
900  
905  
910  
915  
920  
925  
930  
935  
940  
945  
950  
955  
960  
965  
970  
975  
980  
985  
990  
995

5. The method according to claim 4, wherein the retentate is fed to the electrodialysis unit between the anion exchange membrane and the cation exchange membrane, and also between the univalent anion-selective membrane and the univalent cation-selective membrane, wherein the solution exiting from between the anion exchange membrane and the cation exchange membrane is recycled to the feed to the reverse osmosis unit, and wherein all or a portion of the solution exiting from between the univalent anion-selective membrane and the univalent cation-selective membrane is optionally fed to a magnesium recovery unit, and/or is recycled by blending with salt water to make up the feed stream to the reverse osmosis unit.

6. The method according to claim 2, wherein the electrodialysis concentrate contains sodium chloride at a concentration that is higher than 20% by weight.

7. The method according to claim 2, further comprising: removing a purge stream from either the retentate or the diluate; feeding the purge stream to a magnesium recovery unit; and recovering magnesium from the purge stream.

8. The method according to claim 2, further comprising: feeding the concentrate to a crystallization unit, optionally after concentrating the concentrate stream by evaporation; and

operating the crystallization unit to produce sodium chloride crystals and a bittern that is concentrated in bromine with respect to the stream that is fed to the crystallization unit.

5            9.        The method according to claim 7, further comprising:  
              feeding the bittern to a bromine recovery unit; and  
              operating the bromine recovery unit to recover bromine from the  
bittern.

10           10.      A method of producing purified water and sodium chloride  
from salt water that contains sodium chloride, the method comprising:  
              feeding the salt water to a reverse osmosis unit;  
              operating the reverse osmosis unit to separate the salt water into a  
permeate of purified water which is recovered and a retentate that  
15           contains sodium chloride that is concentrated with reference to the salt  
water;  
              feeding the retentate to an electrodialysis unit having a plurality of  
membranes;  
              operating the electrodialysis unit to separate the retentate into a  
20           diluate that is depleted in sodium chloride with reference to the retentate,  
and a concentrate that is concentrated in sodium chloride with reference to  
the retentate;  
              feeding the diluate to a nanofiltration unit;  
              operating the nanofiltration unit to selectively concentrate divalent  
25           ions in the diluate into an NF retentate and to produce an NF permeate  
that is depleted of divalent ions with reference to the diluate, and wherein  
at least a portion of the NF permeate is recycled back to the feed to the  
reverse osmosis unit;  
              feeding the concentrate to a salt-recovery unit; and  
30           operating the salt-recovery unit to recover sodium chloride from the  
concentrate.

11. The method according to claim 10, wherein the salt water is seawater or is a salt water that is different than seawater and which contains sodium chloride and magnesium and bromine, or salts thereof.

5 12. The method according to claim 10, wherein the electrodialysis membranes include at least one univalent-anion selective membrane and at least one univalent-cation selective membrane.

10 13. The method according to claim 10, wherein the electrodialysis membranes include at least one anion exchange membrane, at least one cation exchange membrane, at least one univalent-anion selective membrane and at least one univalent-cation selective membrane.

15 14. The method according to claim 13, wherein the electrodialysis unit comprises an anode and a cathode and wherein at least four adjacent electrodialysis membranes are arranged in the following order from the anode to the cathode: anion exchange, cation exchange, univalent anion-selective, and univalent cation-selective,  
20 wherein the order can be optionally repeated in whole or in part within the plurality of electrodialysis membranes.

25 15. The method according to claim 14, wherein the retentate is fed to the electrodialysis unit between the anion exchange membrane and the cation exchange membrane, and also between the univalent anion-selective membrane and the univalent cation-selective membrane, wherein the solution exiting from between the anion exchange membrane and the cation exchange membrane is recycled to the feed to the reverse osmosis unit, and wherein all or a portion of the solution exiting from  
30 between the univalent anion-selective membrane and the univalent cation-selective membrane is optionally fed to a magnesium recovery unit, or is

recycled by blending with salt water to make up the feed stream to the reverse osmosis unit.

5           16.    The method according to claim 11, wherein the electrodialysis concentrate contains sodium chloride at a concentration that is higher than 20% by weight.

10           17.    The method according to claim 11, further comprising: removing a purge stream from either the retentate or the diluate; feeding the purge stream to a magnesium recovery unit; and recovering magnesium from the purge stream.

15           18.    The method according to claim 11, further comprising: feeding the concentrate stream to a crystallization unit, optionally after concentrating the concentrate stream by evaporation; and operating the crystallization unit to produce sodium chloride crystals and a bittern that is concentrated in bromine with respect to the stream that is fed to the crystallization unit.

20           19.    The method according to claim 18, further comprising: feeding the bittern to a bromine recovery unit; and operating the bromine recovery unit to recover bromine from the bittern.

25           20.    The method according to claim 11, wherein the divalent ions that are selectively concentrated by the nanofiltration unit in the NF retentate comprise magnesium ions, and wherein the method further comprises:

30                feeding the NF retentate to a magnesium recovery unit; operating the magnesium recovery unit to recover magnesium; and recycling at least a part of the NF permeate to the feed to the reverse osmosis unit.

21. The method according to claim 20, further comprising:  
reducing the calcium concentration in the NF retentate prior to  
feeding the NF retentate to the magnesium recovery unit.

5           22. The method according to claim 10, wherein the  
electrodialysis unit is operated at an elevated pressure.

23. The method according to claim 22, wherein the elevated  
pressure is optionally substantially the same as the pressure of the  
10           retentate, or is substantially the same as the pressure of the inlet of the  
nanofiltration unit.

24. A method of producing purified water and sodium chloride  
from salt water that contains sodium chloride, the method comprising:  
15           /           feeding the salt water to a reverse osmosis unit;  
operating the reverse osmosis unit to separate the salt water into a  
permeate of purified water which is recovered and a retentate that  
contains sodium chloride that is concentrated with reference to the salt  
water;  
20           feeding the retentate to an electrodialysis unit that is designed to  
operate at an elevated pressure and which has a plurality of membranes;  
operating the electrodialysis unit at the elevated pressure to  
separate the retentate into a diluate that is depleted in sodium chloride  
with reference to the retentate, and a concentrate that is concentrated in  
25           sodium chloride with reference to the retentate, wherein at least a portion  
of the diluate is recycled back to the feed to the reverse osmosis unit;  
feeding the concentrate to a salt-recovery unit; and  
operating the salt-recovery unit to recover sodium chloride from the  
concentrate.

30

25. The method according to claim 24, wherein the salt water is seawater or is a salt water that is different than seawater and which contains sodium chloride and magnesium and bromine, or salts thereof.

5 26. The method according to claim 24, wherein the electro dialysis membranes include at least one univalent-anion selective membrane and at least one univalent-cation selective membrane.

10 27. The method according to claim 24, wherein the electro dialysis membranes include at least one anion exchange membrane, at least one cation exchange membrane, at least one univalent-anion selective membrane and at least one univalent-cation selective membrane.

15 28. The method according to claim 27, wherein the electro dialysis unit comprises an anode and a cathode and wherein at least four adjacent electro dialysis membranes are arranged in the following order from the anode to the cathode: anion exchange, cation exchange, univalent anion-selective, and univalent cation-selective, wherein the order can be optionally repeated in whole or in part within the plurality of electro dialysis membranes.

20

25 29. The method according to claim 28, wherein the retentate is fed to the electro dialysis unit between the anion exchange membrane and the cation exchange membrane, and also between the univalent anion-selective membrane and the univalent cation-selective membrane, wherein the solution exiting from between the anion exchange membrane and the cation exchange membrane is recycled to the feed to the reverse osmosis unit, and wherein all or a portion of the solution exiting from between the univalent anion-selective membrane and the univalent cation-selective membrane is optionally fed to a magnesium recovery unit and/or is recycled by blending with salt water to make up the feed stream to the reverse osmosis unit.

30

30. The method according to claim 28, wherein the electrodialysis concentrate contains sodium chloride at a concentration that is higher than 20% by weight.

5

31. The method according to claim 25, further comprising:  
removing a purge stream from either the retentate or the diluate;  
feeding the purge stream to a magnesium recovery unit; and  
recovering magnesium from the purge stream.

10

32. The method according to claim 25, further comprising:  
feeding the concentrate to a crystallization unit, optionally after  
concentrating the concentrate stream by evaporation; and  
operating the crystallization unit to produce sodium chloride crystals  
and a bittern that is concentrated in bromine with respect to the stream  
that is fed to the crystallization unit.

15

33. The method according to claim 32, further comprising:  
feeding the bittern to a bromine recovery unit; and  
operating the bromine recovery unit to recover bromine from the  
bittern.

20

34. The method according to claim 22, further comprising:  
feeding the diluate to a nanofiltration unit;  
operating the nanofiltration unit to selectively concentrate divalent  
ions in the diluate into an NF retentate and to produce an NF permeate  
that is depleted of divalent ions with reference to the diluate, and wherein  
at least a portion of the NF permeate is recycled back to the feed to the  
reverse osmosis unit;

25

wherein the divalent ions that are selectively concentrated by the  
nanofiltration unit in the NF retentate comprise magnesium ions;  
feeding the NF retentate to a magnesium recovery unit;

30

operating the magnesium recovery unit to recover magnesium; and  
recycling at least a part of the NF permeate to the feed to the  
reverse osmosis unit.

5           35.    The method according to claim 34, further comprising:  
              reducing the calcium concentration in the NF retentate prior to  
              feeding the NF retentate to the magnesium recovery unit.

10           36.    The method according to claim 24, wherein the elevated  
              pressure is substantially the same as the pressure of the retentate, or is  
              substantially the same as the inlet pressure of the nanofiltration unit.

15           37.    An apparatus for recovering sodium chloride and purified  
              water from salt water containing sodium chloride, the apparatus  
              comprising:  
              a pump that is designed to feed salt water from a source of salt  
              water to  
              a reverse osmosis unit that is designed to produce a permeate of  
              purified water and a retentate that contains sodium chloride that is  
20           concentrated with reference to the salt water, wherein the reverse osmosis  
              unit is operatively connected to transfer the retentate to  
              an electrodialysis unit comprising a plurality of ion-exchange  
              membranes, wherein at least one membrane is a univalent anion-selective  
              membrane and at least one other membrane is a univalent cation-selective  
25           membrane, and wherein the electrodialysis unit is designed to separate  
              the retentate into a diluate that is depleted in sodium chloride with  
              reference to the retentate, and a concentrate that is concentrated in  
              sodium chloride with reference to the retentate, wherein the electrodialysis  
              unit is operatively connected to transfer at least a portion of the diluate to  
30           the feed to the reverse osmosis unit, and is also operatively connected to  
              transfer the concentrate to

a salt-recovery unit that is designed to recover sodium chloride from the concentrate.

5           38.    The apparatus according to claim 37, wherein the salt water is seawater or a salt water that is different than seawater and which contains sodium chloride and magnesium and bromine, or salts thereof.

10           39.    The apparatus according to claim 37, wherein the electrodialysis membranes include at least one anion exchange membrane, at least one cation exchange membrane, at least one univalent-anion selective membrane and at least one univalent-cation selective membrane.

15           40.    The apparatus according to claim 39, wherein the electrodialysis unit comprises an anode and a cathode and wherein at least four adjacent electrodialysis membranes are arranged in the following order from the anode to the cathode: anion exchange, cation exchange, univalent anion-selective, and univalent cation-selective, wherein the order can be optionally repeated in whole or in part within the plurality of electrodialysis membranes.

20           41.    The apparatus according to claim 38, wherein the electrodialysis unit is designed to produce a concentrate that contains sodium chloride at a concentration of at least 20%.

25           42.    The apparatus according to claim 38, further comprising:  
          an operative connection to transfer a purge stream from either the retentate or the diluate to a magnesium recovery unit; and wherein the salt recovery unit comprises:

30           an evaporator that is designed to concentrate either the retentate or the diluate to the extent that the stream is saturated in sodium chloride, and wherein the evaporator is operatively connected to a

crystallization unit that is designed to produce sodium chloride crystals and a bittern that is concentrated in bromine with respect to the stream that is fed to the crystallization unit; and

an operative connection to transfer the bittern to a bromine recovery unit that is designed to recover bromine from the bittern.

43. An apparatus for recovery of sodium chloride and purified water from salt water containing sodium chloride, the apparatus comprising:

a pump that is designed to feed salt water from a source of salt water to

a reverse osmosis unit that is designed to produce a permeate of purified water and a retentate that contains sodium chloride that is concentrated with reference to the salt water and, wherein the reverse osmosis unit is operatively connected to transfer the retentate to

an electrodialysis unit which is designed to separate the retentate into a diluate that is depleted in sodium chloride with reference to the retentate, and a concentrate that is concentrated in sodium chloride with reference to the retentate, wherein the electrodialysis unit is operatively connected to transfer the concentrate to

a salt-recovery unit that is designed to recover sodium chloride from the concentrate, and wherein the electrodialysis unit is operatively connected to transfer at least a portion of the diluate to

a nanofiltration unit that is designed to selectively concentrate divalent ions in the diluate into an NF retentate and to produce an NF permeate that is depleted of divalent ions with reference to the diluate, and wherein the nanofiltration unit is operatively connected to recycle at least a portion of the NF permeate back to the feed to the reverse osmosis unit.

44. The apparatus according to claim 43, wherein the salt water is seawater or a salt water that is different than seawater and which contains sodium chloride and magnesium and bromine, or salts thereof.

45. The apparatus according to claim 43, wherein the electrodialysis membranes include at least one univalent-anion selective membrane and at least one univalent-cation selective membrane.

5

46. The apparatus according to claim 43, wherein the electrodialysis membranes include at least one anion exchange membrane, at least one cation exchange membrane, at least one univalent-anion selective membrane and at least one univalent-cation selective membrane.

10

47. The apparatus according to claim 46, wherein the electrodialysis unit comprises an anode and a cathode and wherein at least four adjacent electrodialysis membranes are arranged in the following order from the anode to the cathode: anion exchange, cation exchange, univalent anion-selective, and univalent cation-selective, wherein the order can be optionally repeated in whole or in part within the plurality of electrodialysis membranes.

15

48. The apparatus according to claim 45, wherein the electrodialysis unit is designed to produce a concentrate that contains sodium chloride at a concentration that is higher than 20% by weight.

20

49. The apparatus according to claim 43, further comprising:  
an operative connection to transfer a purge stream from either the retentate or the diluate to a magnesium recovery unit; and wherein the salt recovery unit comprises:

25

an evaporator that is designed to concentrate either the retentate or the diluate to the extent that the stream is saturated in sodium chloride, and wherein the evaporator is operatively connected to a crystallization unit that is designed to produce sodium chloride crystals and a bittern that is concentrated in bromine with respect to the

30

stream that is fed to the crystallization unit; and wherein the apparatus further comprises

an operative connection to transfer the bittern to a bromine recovery unit that is designed to recover bromine from the bittern.

5

50. The apparatus according to claim 43, wherein the divalent ions that are selectively concentrated by the nanofiltration unit in the NF retentate comprise magnesium ions, and wherein the apparatus further comprises:

10

an operative connection to transfer retentate to a magnesium recovery unit that is designed to recover magnesium, and which has an operative connection to recycle at least a part of the NF permeate to the feed to the reverse osmosis unit.

15

51. The apparatus according to claim 43, wherein the electrodialysis unit is designed to operate at an elevated pressure.

20

52. The apparatus according to claim 51, wherein the elevated pressure is optionally the pressure of the retentate, or the pressure of the inlet of the nanofiltration unit.

25

53. An apparatus for recovery of sodium chloride and potable water from salt water comprising:

a pump that is designed to feed salt water from a source of salt water to

30

a reverse osmosis unit that is designed to produce a permeate stream of potable water and a retentate stream that contains sodium chloride that is concentrated with reference to the salt water, and wherein the reverse osmosis unit is operatively connected to transfer the retentate to

an electrodialysis unit that is designed to operate at elevated pressure and is designed to separate its feed into a diluate that is depleted

in sodium chloride with reference to the feed, and a concentrate that is concentrated in sodium chloride with reference to the feed, wherein the electro dialysis unit is operatively connected to recycle at least a portion of the diluate back to the feed to the reverse osmosis unit, and wherein the electro dialysis unit is operatively connected to transfer the concentrate to a salt-recovery unit that is designed to recover sodium chloride from the concentrate.

54. The apparatus according to claim 53, wherein the salt water is seawater or a salt water that is different than seawater and which contains sodium chloride and magnesium and bromine, or salts thereof.

55. The apparatus according to claim 54, wherein the electro dialysis membranes include at least one univalent-anion selective membrane and at least one univalent-cation selective membrane

56. The apparatus according to claim 55, wherein the electro dialysis membranes include at least one anion exchange membrane, at least one cation exchange membrane, at least one univalent-anion selective membrane and at least one univalent-cation selective membrane.

57. The apparatus according to claim 56, wherein the electro dialysis unit comprises an anode and a cathode and wherein at least four adjacent electro dialysis membranes are arranged in the following order from the anode to the cathode: anion exchange, cation exchange, univalent anion-selective, and univalent cation-selective, wherein the order can be optionally repeated in whole or in part within the plurality of electro dialysis membranes.

58. The apparatus according to claim 54, further comprising:  
an operative connection to transfer a purge stream from either the  
retentate or the diluate to a magnesium recovery unit; and wherein the salt  
recovery unit comprises:

5 an evaporator that is designed to concentrate either the retentate or  
the diluate to the extent that the stream is saturated in sodium chloride,  
and wherein the evaporator is operatively connected to a

crystallization unit that is designed to produce sodium chloride  
crystals and a bittern that is concentrated in bromine with respect to the  
10 stream that is fed to the crystallization unit; and wherein the apparatus  
further comprises an operative connection to transfer the bittern to a  
bromine recovery unit that is designed to recover bromine from  
the bittern.

15 59. The apparatus according to claim 53, wherein the elevated  
pressure is substantially the same as the pressure of the retentate exiting  
the reverse osmosis unit.

20 60. The apparatus according to claim 53, wherein the  
electrodialysis unit is operatively connected to transfer at least a portion of  
the diluate to a nanofiltration unit that is designed to operate at an inlet  
pressure to selectively concentrate divalent ions in the diluate into an NF  
retentate and to produce an NF permeate that is depleted of divalent ions  
with reference to the diluate, and wherein the nanofiltration unit is  
25 operatively connected to recycle at least a portion of the NF permeate  
back to the feed to the reverse osmosis unit; and wherein the elevated  
pressure is substantially the same as the inlet pressure of the  
nanofiltration unit.